HIGH EFFICIENCY READ DIODE AMPLIFIER

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Abstract

Impedance characteristics of Read-profile IMPATT diodes are evaluated and amplifiers operating in the stable reflective mode have been designed based on the measured diode impedance. Power output of up to 4.5 Watts was obtained in a one stage single diode amplifier with a gain of 4.5 dB and an efficiency of 22 percent.

Introduction

Most of the IMPATT diodes developed in the 1960's were PN junction and Schottky-barrier devices with uniform doping profiles. In 1972 Kramer, et al[1] and Salmer, et al[2] successfully demonstrated the high efficiency property of GaAs IMPATT diodes with doping profiles similar to the one proposed originally by Read[3]. Subsequently, high power diodes with efficiencies as high as 35 percent were reported by Kim, et al[4,5]. These Read-type diodes offer a promise of extending the power output and efficiency of IMPATT diode amplifiers beyond current capabilities attainable with uniformly doped diodes. To realize a suitable amplifier circuit, the impedance characteristics of the diode must first be established. In this paper, we will describe the impedance characteristics of GaAs Read diodes and compare them to known characteristics of normal IMPATT diodes with uniform doping profile. We will then discuss design considerations for power amplifiers operating in the stable reflective mode and their performance.

Diode Characterization

Diodes were fabricated from vapor phase epitaxial GaAs with low-high-low modified Read doping profiles and Pt Schottky-barrier contacts[4,5]. The diodes were mounted in Raytheon Type 16 threaded stud packages with typical parasitic capacitance of 0.3 pF and lead inductance of 0.25 nH. The small-signal diode impedance was measured in a 50 ohm microstrip circuit using a network analyzer. Fig. 1 shows an example of the measured results plotted on a Smith Chart (with negative real coordinate). The breakdown voltage of this particular diode was 24.2 Volts, and its capacitance at zero bias was 10.1 pF. At low bias currents, the diode has a negative resistance over the entire X-band. As the bias current increases, the magnitude of the diode negative resistance increases to a maximum value and then decreases, in marked contrast to uniformly doped IMPATT diodes. When used in a reflection type amplifier, this diode would exhibit a gain saturation phenomenon as the bias current is increased. The optimum bias current for the maximum small-signal negative resistance varies with frequency. The reactive parts of the diode impedance also change with the bias current, with the impedance locus almost forming a loop. The shape of the loop is also a function of frequency. For normal GaAs IMPATT diodes (in the same package) the small-signal reactance is always a monotonically decreasing function of the bias current.

The magnitude of the diode's negative Q, which limits the small-signal gain-bandwidth product, may be estimated from the impedance plot. It was calculated to be 7 at 100 mA, decreased to 3.8 at 160 mA, and then increased again to 5.8 at 200 mA. These values may be compared to the Q of normal IMPATT diodes which are typically in the neighbothood of 10 and relatively insensitive to the bias current. Because of the low diode Q, one could obtain a larger gain-bandwidth product with an amplifier using Read-type GaAs IMPATT diodes.

Diodes with higher breakdown voltages ($V_B \sim 50$ V) were also evaluated, and a representative result is plotted in Fig. 2. The center frequency of the negative resistance shifted to a low X-band frequency as expected from the frequency-breakdown voltage relationship of normal IMPATT diodes.

Impedance of the diode was also measured as a function of the RF drive level and plotted in Fig. 3. Both the real part and the reactive part of the diode impedance vary as the power input increases. The impedance of Read diodes is much more sensitive to the RF power level than that of normal IMPATT diodes. This sensitivity of device impedance to the power level will result in a drastic change in the frequency response of the amplifier. Some compromise between the small signal and the large signal characteristics must be exercised in the amplifier circuit design. A small-signal peak gain of about 20 dB with a narrow-band response, for instance, leads to a broadband gain of 4 - 5 dB at large signal levels.

Amplifier Design And Performance

A microstrip amplifier circuit with a one step low impedance transformer was fabricated on an alumina substrate with a thickness of 0.025 inches. The diode, whose impedance characteristic was previously shown in Fig. 1, was used in this amplifier. The amplifier gain responses measured at various input power levels are plotted in Fig. 4. The peak gain compresses down rapidly, while the gain at the low edge of the band expands as the input power is increased. For frequencies below 9 GHz, the amplifier response shifted from a lossy state at small signal levels to an amplifying state with a gain of several dB at large signal levels. The frequency of peak gain was shifted downward with the drive. Similar frequency shifting and gain compression and expansion are also observed in normal IMPATT diodes; however, these phenomena are more pronounced in the Read-diode amplifiers.

The diode was biased through a fixed series resistor of 37 ohms from an adjustable voltage power supply. The voltage was adjusted to 59 Volts for which the bias current was 200 mA at small-signal power input. As the RF power to the amplifier was increased above +27 dBm input, the bias current increased automatically. The bias current increased to 207 mA at +27 dBm input, 222 mA at 30 dBm, 229 mA at 31 dBm, and 239 mA at 32 dBm input. This current increase occurs as the voltage across the diode drops at large RF drives due partially to the junction cooling effect as diodes operate in the higher efficiency mode and partially to the rectification effect. The automatic current variation compensates the gain compression under large RF drives. It also improves the linearity of the amplifier response. The power output of this amplifier for input drive levels greater than +27 dBm is plotted in Fig. 5. Two to three Watts of output power were measured from 8 to 10.5 GHz at +30 dBm (1 Watt) input.

A diode with a higher breakdown voltage which has an impedance characteristic similar to Figures 2 and 3 was also tested in the amplifier circuit. The maximum power output of this amplifier was 4.5 Watts. It had a gain of 4.5 dB from 8.0 to 8.5 GHz with an efficiency of 22 percent.

Noise characteristics of a GaAs Read-type diode amplifier were also evaluated. In a one-stage amplifier, no noticeable FM noise was observed above the background FM noise in the measuring system. The background FM noise measured over a 1.74 KHz band referenced to 140 KHz RMS deviation was -63 dB at 1 KHz from carrier and decreased to -80 dB 100 KHz from carrier. AM noise figures were measured at bias currents from 120 mA to 160 mA in 20 mA increments. The measured noise figures were 38 ± 0.5 dB within the bias range. These noise figures are about 10 dB higher than those of the normal GaAs IMPATT diode amplifiers. Preliminary measurements of noise output of Read diode oscillators (both free-running and injection locked) showed that the noise measured varied between 40 and 60 dB depending on operating conditions.

Conclusion

Read-type GaAs IMPATT diodes have a higher magnitude of negative resistance and lower diode Q than normal IMPATT diodes. The impedance characteristics are sensitive to the bias current and the RF drive. With a proper compromise between the small-signal and the large signal impedance characteristics, stable amplifiers operating with efficiencies approaching that of Read-diode oscillators and a limited dynamic range can be designed.

References

1. B. Kramer, A. Farrayre, L. Hollan, E. Constant, and G. Salmer, "A 22 Percent CW Efficiency Solid State Microwave Oscillator", IEEE G-MTT International Microwave Symposium, Chicago, Illinois, May, 1972, pp. 187-189.

2. G. Salmer, J. Pribetich, A. Farrayre, and B. Kramer, "Theoretical and Experimental Study of GaAs IMPATT Oscillator Efficiency", J. Appl. Phys., Vol. 44, No. 1, January 1973, pp. 314-324.

3. W. T. Read, Jr., "A Proposed High Frequency Negative Resistance Diode", BSTJ, Vol. 27, No. 2, March 1948, pp. 401-446.

4. C. Kim, S. Steele, and R. Bierig, "High Power High Efficiency Operation of Read Type IMPATT Diope Oscillators", Electronic Letters, Vol. 9, No. 8/9, May 3, 1973, pp. 173-174.

5. C. Kim, W. Matthei, and S. Steele, "GaAs Read IMPATT Diode Oscillators", Presented at the Cornell Conference on Microwave Semiconductor Devices, Circuits and Applications, Cornell University, Ithaca, New York, August 16, 1973.

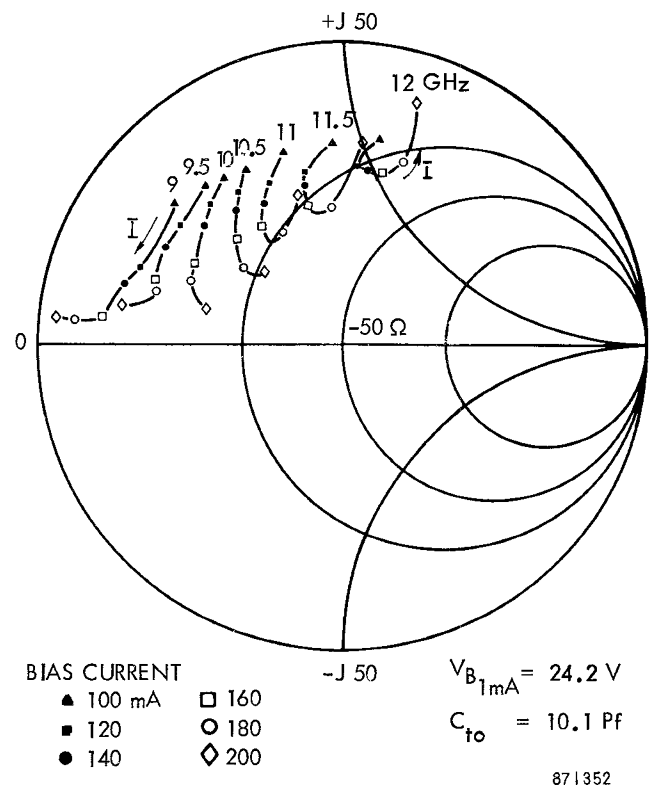

Fig. 1 Diode impedance characteristic at various bias currents

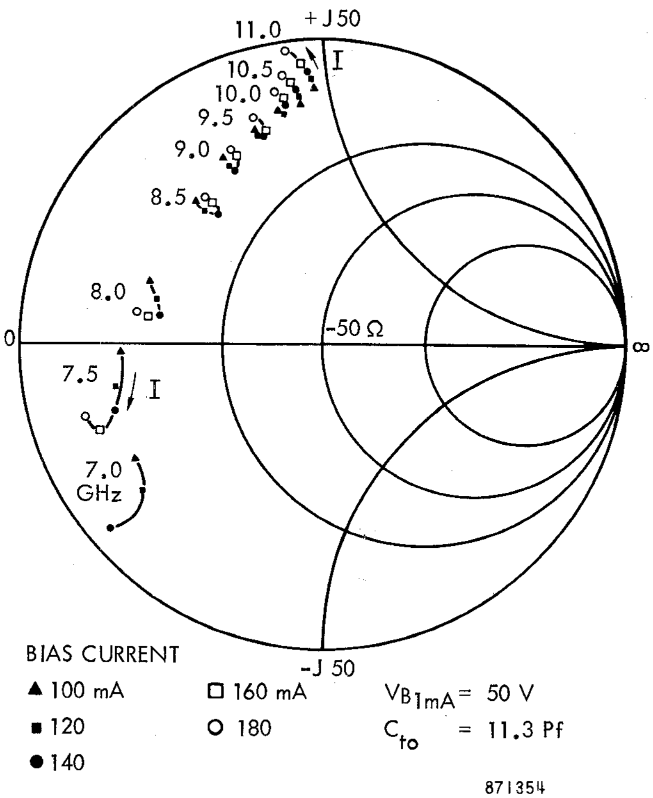

Fig. 2 Diode impedance characteristic for a higher breakdown voltage diode

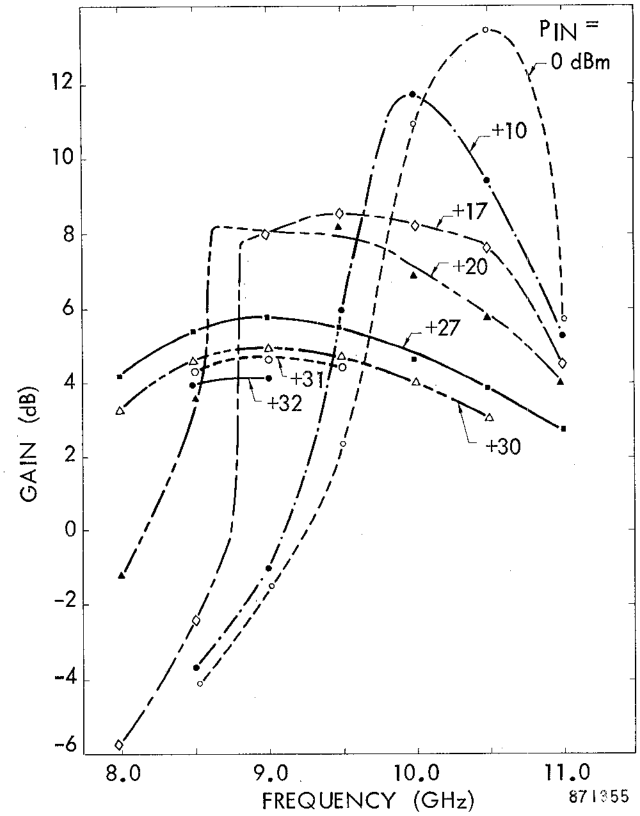

Fig. 4 Amplifier gain response

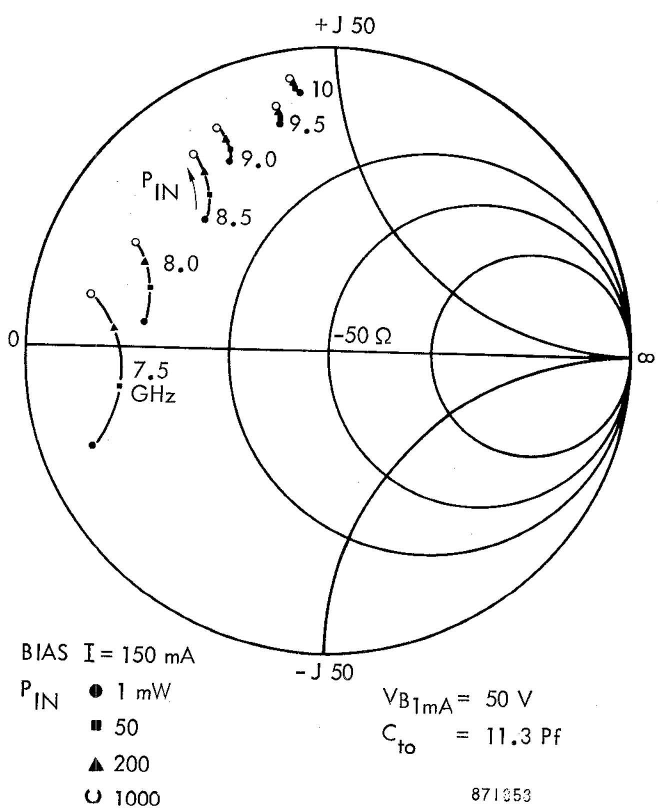

Fig. 3 Diode impedance characteristic at various input power levels

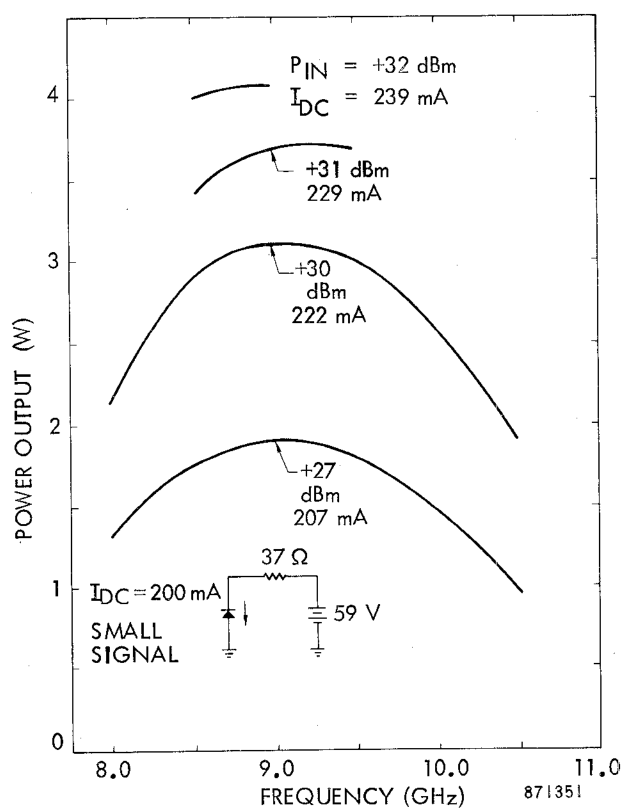

Fig. 5 Amplifier output response